

Plans for future B factories

P. KRIŽAN

Faculty of Mathematics and Physics, University of Ljubljana, Ljubljana, Slovenia

J. Stefan Institute, Ljubljana, Slovenia

The paper discusses future experiments at super B factories. It presents the physics motivation and the tools, accelerators and detectors, and reviews the status of the two projects, SuperKEKB/Belle-II in Japan and SuperB in Italy.

PRESENTED AT

CKM2010, the 6th International Workshop on the CKM
Unitarity Triangle, University of Warwick, UK, 6-10
September 2010

1 Introduction

The two B factories, PEP-II with BaBar and KEKB with Belle, have been a real success story. They were built with the primary goal of measuring CP violation in the B system. From the discovery of large CP violation in 2001, the B factory results evolved into a precision measurement of the CP violation parameter $\sin 2\phi_1 = \sin 2\beta = 0.655 \pm 0.024$ in $B \rightarrow J/\psi K^0$ decays [1, 2, 3]. The constraints from measurements of angles and sides of the unitarity triangle show a remarkable agreement [4, 5, 6], which significantly contributed to the 2008 Nobel prize awarded to Kobayashi and Maskawa. The two B factories also observed direct CP violation in B decays, measured rare decay modes of B mesons, and observed mixing of D^0 mesons. They measured CP violation in $b \rightarrow s$ transitions, thus probing new sources of CP violation. The study of forward-backward asymmetry in $b \rightarrow sl^+l^-$ has by now become a powerful tool in the search for physics beyond the Standard Model (SM). Both collaborations also searched for lepton flavor violating τ decays, and, last but not least, observed a long list of new hadrons, some of which do not seem to fit into the standard meson and baryon schemes. All this was only possible because of the fantastic performance of the accelerators, much beyond their design values. In the KEKB case, the peak luminosity reached a world record value of $2.1 \times 10^{34} \text{cm}^{-2}\text{s}^{-1}$, exceeding the design value by a factor of more than two. The two collaborations have accumulated data samples corresponding to integrated luminosities of 0.557ab^{-1} (BaBar) and 1.041ab^{-1} (Belle).

While B factories were built to check whether the SM with the CKM matrix is correct, the next generation of B factories (super B factories) will have to show in which way the SM is wrong. To search for departures from the Standard model, a ≈ 50 times bigger data sample of decays of B and D mesons and τ leptons is needed, corresponding to an integrated luminosity of $50\text{-}75 \text{ab}^{-1}$. A substantial upgrade is therefore required both of the accelerator complex as well as of the detector [7]. Note, however, that it will be a different world in four years, when the first super B factory starts to operate; there will be serious competition from the LHCb and BESIII experiments. Still, e^+e^- colliders operating at (or near) the $\Upsilon(4S)$ resonance will have considerable advantages in several classes of measurements, e.g., with final states involving neutral particles (γ, π^0) and neutrinos, and will be complementary in many more.

In what follows we shall first discuss the physics motivation, the accelerators and detectors, and then we shall review the status of the two projects, SuperKEKB/Belle-II in Japan and SuperB in Italy.

2 Physics motivation

Examples of particularly challenging measurements which are only possible at a B factory are the studies of B meson decays with more than one neutrino in the final state. Such a process is the leptonic decay $B \rightarrow \tau \nu_\tau$ which is followed by the decay of the τ lepton with one or two additional neutrinos in the final state. In the SM, this transition proceeds via W annihilation, but in some new physics (NP) extensions it could also be mediated by a charged Higgs boson [8]. The measured branching fraction can therefore be used to set limits on the two parameters, the charged Higgs mass and the ratio of vacuum expectation values, $\tan \beta$. As shown in Fig. 1, with the present measurements (green) it is possible to exclude a sizable part of the parameter space; with a data sample corresponding to a luminosity of 50 ab^{-1} , the five standard deviations discovery region covers a substantial fraction of the parameter space (red). The sensitivity is comparable to direct searches with large data sets at the LHC.

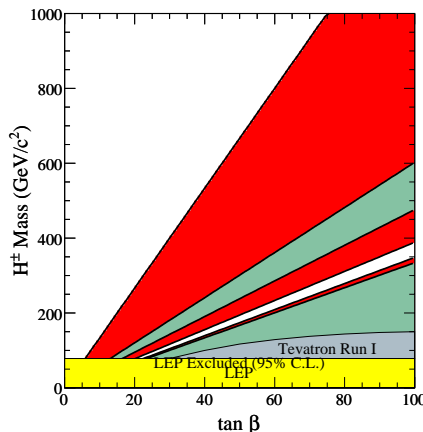


Figure 1: Five standard deviations discovery region (red) for the charged Higgs boson in the $(m_{H^\pm}, \tan \beta)$ plane, from the measurement of $\mathcal{B}(B^+ \rightarrow \tau^+ \nu)$ with 50 ab^{-1} [9]. Other shaded regions show the current 95% C.L. exclusion region.

Such rare processes are searched for in the following way [10]. First, one of the B mesons is fully reconstructed in a number of exclusive decay channels like $B \rightarrow D^{(*)} \pi$. Because of the exclusive associated production of B meson pairs in a B factory, the remaining particles in the event must be the decay products of the associated B . In the $B^- \rightarrow \tau^- \bar{\nu}_\tau$, $\tau^- \rightarrow \mu^- \nu_\tau \bar{\nu}_\mu$, $e^- \nu_\tau \bar{\nu}_e$, $\pi^- \nu_\tau$, decay sequences, only one charged particle is detected. To exclude background events with additional neutral particles (π^0 or γ) in the final state, we use the remaining energy in the calorimeter which is not associated with reconstructed charged tracks. In this measurement we greatly profit from the excellent hermeticity of the spectrometers of the B factories.

A similar process, $B \rightarrow D\tau\bar{\nu}_\tau$ is sensitive to the charged Higgs boson as well [11]. Compared to $B \rightarrow \tau\nu_\tau$, it has a smaller theoretical uncertainty, a larger branching fraction [12, 13], and the differential distributions can be used to discriminate the contributions of W^+ and H^+ . It is worth noting that while LHC experiments are sensitive to $H - b - t$ coupling, in $B \rightarrow \tau\nu_\tau$ and $B \rightarrow D\tau\bar{\nu}_\tau$ we probe the $H - b - u$ and $H - b - c$ couplings.

The decay $B \rightarrow K^{(*)}\nu\bar{\nu}$ has a similar event topology as $B^- \rightarrow \tau^-\bar{\nu}_\tau$, and a similar event analysis can be applied to it as well. By simultaneously measuring the branching fractions for the two decay types and comparing them to the SM predictions (4×10^{-6} for $K\nu\bar{\nu}$ and 6.8×10^{-6} for $K^*\nu\bar{\nu}$, with contribution from penguin box diagrams) it is possible to determine the contributions of anomalous right-handed and left-handed couplings [14, 9, 16].

Yet another example of a decay which cannot be studied at LHCb is a measurement of CP violation in $B \rightarrow K_S\pi^0\gamma$ decays in a search for right-handed currents. The present uncertainty in the time-dependent CP violation parameter S is about 0.2, and should be reduced to a few percent level with 50 ab^{-1} of data.

Super B factories will also be used to search for lepton flavour violating decays of τ leptons, in particular in the $\mu\gamma$ and $\ell\ell\ell$ final state. Theoretical predictions for branching fractions of these two decay modes are between 10^{-10} and 10^{-7} for various extensions of SM (mSUGRA+seesaw, SUSY+SO(10), SM+seesaw, non-universal Z^0 , SUSY+Higgs). The reach of super B factories (from 10^{-9} to 10^{-8} , depending on the decay mode) will allow probing of these predictions and discrimination between the different NP theories [15].

Two recent publications summarize the physics potential of a super B factory, one prepared by Belle-II authors and guests [9], and the other by SuperB collaborators and guests [16]. To summarize, there is a good chance to see new phenomena, such as CP violation in B decays from new physics sources, or lepton flavor violation in τ decays. The Super B factory results will help to diagnose or constrain new physics models. $B \rightarrow \tau\bar{\nu}_\tau$ and $B \rightarrow D^{(*)}\tau\bar{\nu}_\tau$ decays can probe the charged Higgs contribution in the large $\tan\beta$ region. The physics motivation for a super B factory is independent of LHC. If LHC experiments find new physics phenomena, precision flavour physics is compulsory to understand it; if no new physics is found at LHC, high statistics B and τ decays would be a unique way to search for new physics above the TeV scale (or at the TeV scale in case of the minimal flavour violation scenario). Needless to say that there are many more topics to explore, including CP violation searches for charmed hadrons, searches for new hadrons etc.

It is worthwhile to refer to a lesson from history: the top quark mass was first estimated through the observation of $B^0 - \bar{B}^0$ mixing at ARGUS, and it took seven more years to directly observe it and measure its mass at the CDF and D0 experiments. Similarly, the prediction of the charm quark came from the observed absence of flavour changing neutral currents via the GIM mechanism. Its mass could be

	SuperKEKB		SuperB		
	LER (e^+)	HER (e^-)	LER (e^-)	HER (e^+)	
Energy	4.0	7.0	4.18	6.7	GeV
Half crossing angle	41.5		33		mrad
Horizontal emittance	3.2	4.3	1.82	1.97	nm
Emittance ratio	0.27	0.25	0.34	0.25	%
Beta functions at IP (x/y)	32 / 0.27	25 / 0.31	32 / 0.205	26 / 0.253	mm
Beam currents	3.6	2.6	1.82	1.97	A
Beam-beam parameter	0.0886	0.0830	0.0970	0.0971	
Luminosity	8×10^{35}		1×10^{36}		$\text{cm}^{-2}\text{s}^{-1}$

Table 1: SuperKEKB and SuperB: parameters of the low energy (LER) and high energy (HER) accelerator rings.

estimated from the observed K^0 mixing rate.

3 Accelerators

To search for departures from the SM, a ≈ 50 times larger data sample is needed. For such an increase in the data sample, a sizable upgrade of the B factory accelerator complex is required leading to a 40 times larger peak luminosity. These next generation accelerators are known as super B factories. There are two super B factory projects under way. The first one, SuperKEKB, foresees a substantial redesign of elements of the existing KEKB accelerator complex while retaining the same tunnel and related infrastructure. After 11 years of successful operation, the last KEKB beam was ceremonially aborted on June 30, 2010. This opened the way for the construction of SuperKEKB. To increase the luminosity by a factor of 40 the plan is to modestly increase the current (by a factor of 2) with respect to the KEKB values, and dramatically shrink the beam size at the collision point, while the beam beam parameter is kept at the KEKB value (Table 1). In this 'nano-beam' scheme which was invented by Pantaleo Raimondi for the Italian SuperB project [17], the beams collide at a rather large angle of 83 mrad (compared to 22 mrad in KEKB). In addition, a lower beam asymmetry of 7 GeV and 4 GeV instead of 8 GeV and 3.5 GeV is needed to reduce the beam losses due to Touschek scattering in the lower energy beam.

The modifications of the KEKB complex include: improvements in electron injection, a new positron target and damping ring, redesign of the lattices of the low energy (LER) and high energy (HER) rings, replacing short dipoles with longer ones (LER), installing TiN-coated beam pipe with ante-chambers, modifications of the RF

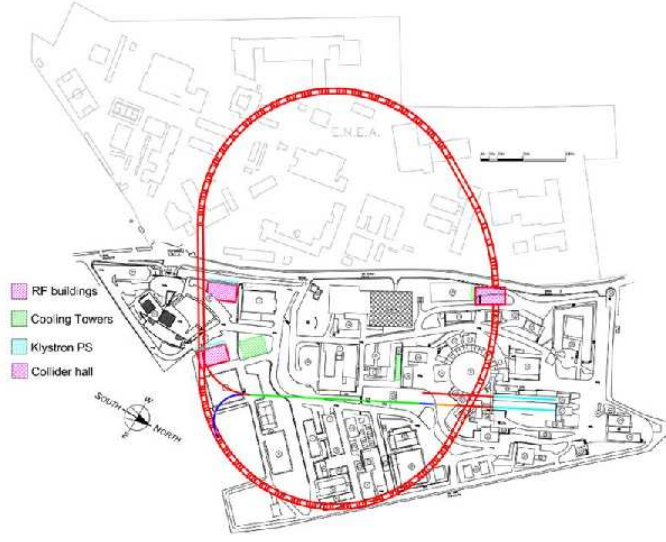


Figure 2: The new SuperB accelerator complex at one of the possible sites, the Frascati National Laboratory.

system, and a completely redesigned interaction region [18].

Another approach to the design of a super B factory will be exploited in the Italian SuperB project [19]. Here it is foreseen that a new tunnel will be built (Fig. 2); the site will be chosen early in 2011. Parts of the beam elements of PEP-II will be reused in the accelerator construction. In addition to the nano-beam scheme (Table 1), an essential feature of the SuperB accelerator is the crab waist collision of two beams in which special sextupoles will be used close to the interaction region to maximize the overlap of the two beams. This scheme was successfully tested at the DAΦNE ring by Pantaleo Raimondi and his team [20]. The SuperB accelerator is designed in such a way that it can be modified to run at the $\psi(3770)$ resonance close to charm threshold, where pairs of D^0 mesons are produced in a coherent $L = 1$ state. Data accumulated at charm threshold would allow precision charm mixing, CP violation and CPT violation studies. Another feature of the SuperB accelerator will be the polarization of the low energy (electron) beam. This could increase the sensitivity to lepton flavour violating τ decays and CP violation in τ decays through a reduction of backgrounds [16]. It would also enable a precise $\sin^2 \Theta_W$ measurement.

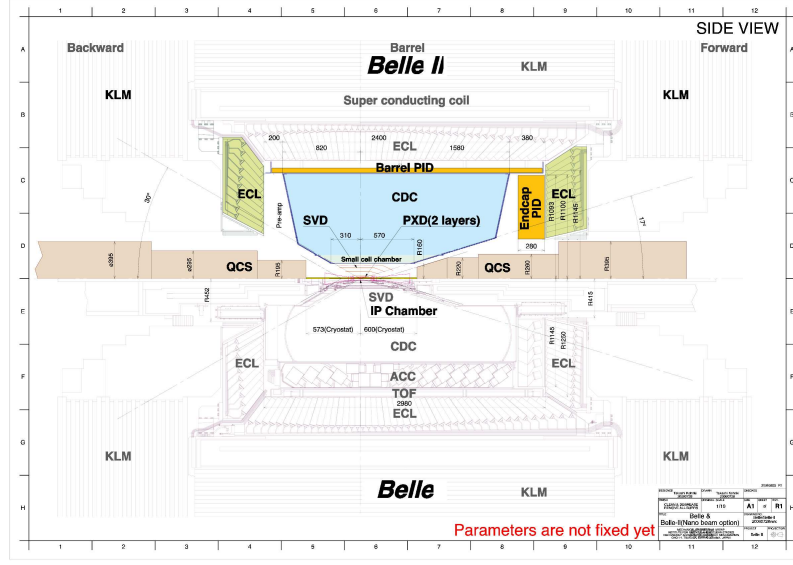


Figure 3: Upgraded Belle II spectrometer (top half) as compared to the present Belle detector (bottom half).

4 Detectors

The planned substantial increase in luminosity requires a careful design of the detectors. To maintain the excellent performance of the spectrometers, the critical issues will be to mitigate the effects of higher backgrounds (by a factor of 10 to 20), leading to an increase in occupancy and radiation damage, as well as fake hits and pile-up noise in the electromagnetic calorimeter. Higher event rates will require substantial modifications in the trigger scheme, DAQ and computing relative to the current experiments. In addition, improved hadron identification is needed, and similarly good (or better) hermeticity is required [18].

For the Belle-II detector (Fig. 3), the following solutions will be adopted [18]. The inner layers of the vertex detector will be replaced with a pixel detector, the inner part of the main tracker (CDC, central drift chamber) will be replaced with a silicon strip detector, a better particle identification device will be used, the CsI(Tl) crystals of the end-cap calorimeter will be replaced by pure CsI, the resistive plate chambers of the end-cap muon and K_L^0 detection system will be replaced by scintillator strips read out by SiPMs, and all components will be read-out by fast readout electronics and an improved computing system.

The new vertex detector will have two pixel layers, at $r = 14$ mm and $r = 22$ mm around a 10 mm radius Be beam pipe, and four double-sided strip sensors at radii of 38 mm, 80 mm, 115 mm, and 140 mm. The pixel detector will be based on

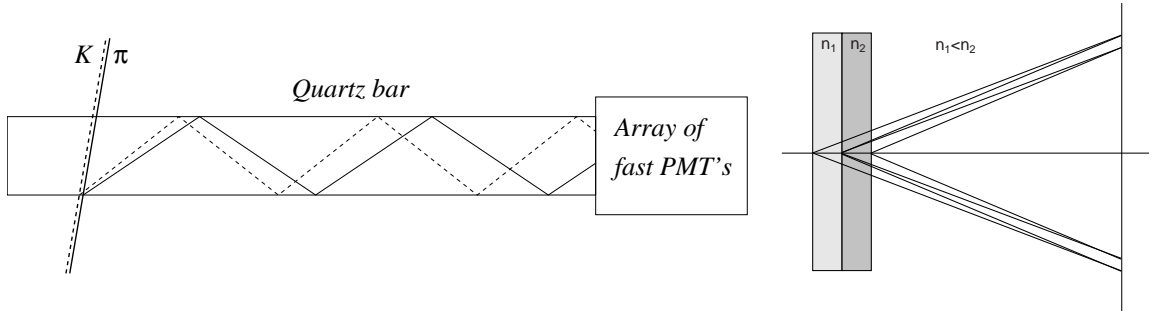


Figure 4: Belle-II PID systems: principle of operation of the TOP counter (left) and of the proximity focusing RICH with a nonhomogeneous aerogel radiator in the focusing configuration (right).

DEPFET sensors [21]. A significant improvement in vertex resolution is expected with respect to Belle, both for low momentum particles (by a factor of two) because of reduced Coulomb scattering, as well as for high momentum particles because the high resolution pixel detector is closer to the beam pipe and interaction point. Another important feature is a significant improvement in K_S^0 reconstruction efficiency (by about 30%) and vertex resolution because of a larger volume covered by the vertex detector.

The hadron particle identification will be provided by a time-of-propagation (TOP) counter in the barrel part, and a RICH with a focusing aerogel radiator in the forward region of the spectrometer. The TOP counter [22] is a kind of DIRC counter with quartz radiator bars in which the two dimensional information from a Cherenkov ring image is represented by the time of arrival and impact position of the Cherenkov photons at the photon detector. At a given momentum, the slower kaons (dotted in Fig. 4) emit Cherenkov photons at a smaller angle than pions; as a result, also their Cherenkov photons propagate longer along the quartz bar. Compared to the DIRC, the TOP counter construction is more compact, since the large expansion volume is not needed as the photon detectors can be coupled directly to the quartz bar exit window. On the other hand, the TOP counter demands photon detectors with single photon time resolution below 100 ps. A 16-channel MCP PMT as developed by Hamamatsu has been investigated for this purpose [22]. For the end-cap region a proximity focusing RICH with aerogel as radiator is being designed. The key issue in the performance of this type of RICH counter is to improve the Cherenkov angle resolution per track by increasing the number of detected photons. With a thicker radiator, the number of detected photons increases, but in a proximity focusing RICH the single photon resolution degrades because of the emission point uncertainty. However, this limitation can be overcome in a proximity focusing RICH with a non-homogeneous radiator [23], where one may achieve overlapping of the corresponding Cherenkov rings

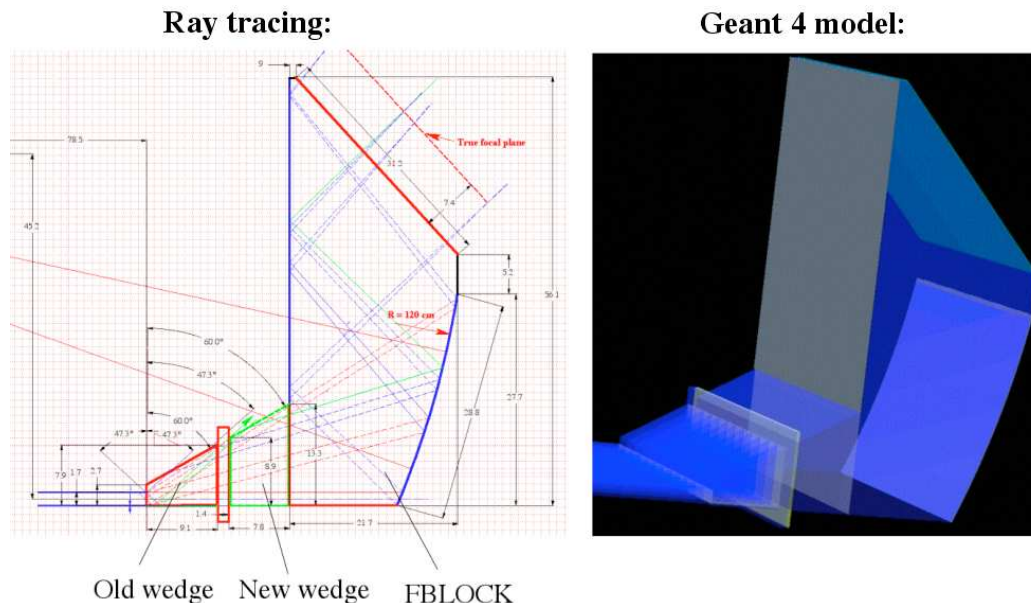


Figure 5: SuperB PID: focusing DIRC counter.

on the photon detector (Fig. 4). This represents a sort of focusing of the photons within the radiator, and eliminates or at least considerably reduces the spread due to emission point uncertainty. Both detectors are expected to considerably improve the particle identification efficiency if compared to Belle; the end-cap RICH will provide a $4\sigma\pi/K$ separation up to kinematic limits, and the barrel TOP counter will identify kaons with an efficiency exceeding 90% at a few percent pion fake probability.

In the new DIRC counter, the large stand-off box with single channel PMTs will be replaced by a compact focusing quartz block and multi-anode PMTs as photon sensors (Fig. 5). By measuring the time of arrival of Cherenkov photons, the fast photon detectors will allow to correct for the chromatic error, i.e., variation of Cherenkov angle with wavelength [25]. The focusing DIRC counter is expected to extend the π/K separation range by improving the angular resolution by about 10%. At the same time, the order-of-magnitude lower mass of the expansion volume will considerably reduce the level of beam induced backgrounds.

5 Status of the projects

The SuperKEKB/Belle-II project has received initial construction funding in 2010 for the positron damping ring, and with the Japanese 'Very Advanced Research Support Program' a sizable fraction of funds for the main ring upgrade (exceeding 100 MUSD) for the period 2010-2012. KEK plans to obtain additional funds to complete the construction as scheduled, i.e., start the SuperKEKB commissioning in the autumn of 2014, and start data taking in 2015. It is expected that by 2017 the first 5 ab^{-1} of data will be collected, and the full data sample of 50 ab^{-1} will be reached in 2020/2021.

The SuperB project is the first in the list of flagship projects of the new Italian national research plan over the next few years. The Italian government has delivered an initial funding for 2010 as a part of a multi-annual funding program. The aim of the project is to accumulate 75 ab^{-1} on a time scale similar to SuperKEKB/Belle-II.

6 Summary

B factories have proven to be an excellent tool for flavour physics, with reliable long term operation, constant improvement of operation, achieving and surpassing design performance. A major upgrade has started at KEK to construct the SuperKEKB accelerator and the Belle-II detector, and be ready for data taking by 2015. The SuperB project in Italy foresees building a new tunnel, reusing and upgrading the PEP-II accelerator and the BaBar detector. Its special features are a polarized electron beam and the ability to operate at the charm threshold. Analysis of the physics reach suggests that we can expect a new and exciting era of discoveries, complementary to the LHC.

References

- [1] K. F. Chen *et al.* [Belle Collaboration], Phys. Rev. Lett. **98**, 031802 (2007).
- [2] B. Aubert *et al.* [BABAR Collaboration], Phys. Rev. D **79**, 072009 (2009).
- [3] Heavy Flavor Averaging Group,
<http://www.slac.stanford.edu/xorg/hfag/triangle/summer2010/index.shtml#sin2b>
- [4] CKMfitter Group (J. Charles *et al.*), Eur. Phys. J. C41, 1-131 (2005) [hep-ph/0406184], updated results and plots available at:
<http://ckmfitter.in2p3.fr>
- [5] UTfit Collaboration, <http://www.utfit.org/UTfit/>

- [6] A. Stocchi, these proceedings
- [7] K. Abe *et al.* (edited by S. Hashimoto, M. Hazumi, J. Haba, J. W. Flanagan and Y. Ohnishi), “Letter of Intent for KEK Super B Factory”, KEK report 2004-04, <http://superb.kek.jp/documents/loi/>; M. Bona *et al.* [SuperB Collaboration], “SuperB: A High-Luminosity Asymmetric e^+e^- Super Flavor Factory. Conceptual Design Report,” arXiv:0709.0451 [hep-ex].
- [8] W. S. Hou, Phys. Rev. D **48**, 2342 (1993).
- [9] T. Aushev *et al.*, arXiv:1002.5012 [hep-ex].
- [10] K. Ikado *et al.* [Belle Collaboration], Phys. Rev. Lett. **97**, 251802 (2006); B. Aubert *et al.* [BABAR Collaboration], Phys. Rev. Lett. **95**, 041804 (2005).
- [11] B. Grzadkowski and W.-S. Hou, Phys. Lett. B **283**, 427 (1992); M. Tanaka, Z. Phys. C **67**, 321 (1995); K. Kiers and A. Soni, Phys. Rev. D **56**, 5786 (1997); H. Itoh, S. Komine, and Y. Okada, Prog. Theor. Phys. **114**, 179 (2005); C.-H. Chen and C.-Q. Geng, JHEP **0610**, 053 (2006); J. F. Kamenik and F. Mescia, Phys. Rev. D **78**, 014003 (2008).
- [12] A. Matyja *et al.* [Belle Collaboration], Phys. Rev. Lett. **99**, 191807 (2007); A. Bozek *et al.* [Belle Collaboration], Phys. Rev. D **82**, 072005 (2010); B. Aubert *et al.* [BABAR Collaboration], Phys. Rev. D **79**, 092002 (2009); B. Aubert *et al.* [BABAR Collaboration], Phys. Rev. Lett. **100**, 021801 (2008); I. Adachi *et al.* [Belle Collaboration], arXiv:0910.4301 [hep-ex].
- [13] A. Bozek, these proceedings, arXiv:1101.2681v1 [hep-ex].
- [14] W. Altmannshofer, A. J. Buras, D. M. Straub and M. Wick, JHEP **0904**, 022 (2009).
- [15] T. Goto, Y. Okada, T. Shindou and M. Tanaka, Phys. Rev. D **77**, 095010 (2008).
- [16] B. O’Leary *et al.* [SuperB Collaboration], arXiv:1008.1541 [hep-ex].
- [17] P. Raimondi, Status of the SuperB Effort,” presentation at the 2nd Workshop on Super B Factory, LNF-INFN, Frascati, March 2006, <http://www.lnf.infn.it/conference/superb06/talks/raimondi1.ppt> (2006).
- [18] T. Abe *et al.*, arXiv:1011.0352 [physics.ins-det].
- [19] M. Biagini *et al.*, arXiv:1009.6178 [physics.acc-ph].
- [20] Section 3 of [19]; M. Zobov *et al.*, Phys. Rev. Lett. **104**, 174801 (2010).

- [21] See for example J. Kemmer, G. Lutz, Nucl. Instr. Meth. A **253** 356 (1987);
I. Peric, Nucl. Instr. Meth. A **579**, 658 (2007).
- [22] K. Inami, Nucl. Instr. and Meth. A **595**, 96 (2008).
- [23] T. Iijima, S. Korpar *et al.*, Nucl. Instr. and Meth. A **548**, 383 (2005).
- [24] E. Grauges *et al.*, arXiv:1007.4241 [physics.inst-det].
- [25] J. Benitez *et al.*, Nucl. Instrum. Meth. A **595**, 104 (2008).